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M03B197/ASB

Patent application number

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0322888.9

Full name, address and postcode of the or of each applicant (underline all surnames)

The BOC Group plc, Chertsey Road, Windlesham, Surrey, GU20 6HJ

Patents ADP number (if you know it)

884627002 7975949001

If the applicant is a corporate body, give the country/state of its incorporation

England

Title of the invention

VACUUM PUMP

Name of your agent (if you have one)

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"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

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I/We request the grant of a patent on the basis of this application.

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VACUUM PUMP

This invention relates to a vacuum pump and in particular a compound vacuum pump with multiple ports suitable for differential pumping of multiple chambers.

5 In a differentially pumped mass spectrometer system a sample and carrier gas are introduced to a mass analyser for analysis. One such example is given in Figure 1. With reference to Figure 1, in such a system there exists a high vacuum chamber 10 immediately following first, (depending on the type of system) second, and third evacuated interface chambers 11, 12, 14. The first interface chamber is the highest-pressure chamber in the evacuated spectrometer system and may contain a capillary through which ions are drawn from the ion source into the first interface chamber 11. The second, optional interface chamber 12 may include a first ion guide for guiding ions from the first interface chamber 11 into the third interface chamber 14, and the third chamber 14 may include a second ion guide for guiding ions from the second interface chamber into the high vacuum chamber 10. In this example, in use, the first interface chamber is at a pressure of around 1-10 mbar, the second interface chamber (where used) is at a pressure of around 10^{-1} -1 mbar, the third interface chamber is at a pressure of around 10^{-2} - 10^{-3} mbar, and the high vacuum chamber is at a pressure of around 10^{-5} - 10^{-6} mbar.

The high vacuum chamber 10, second interface chamber 12 and third interface chamber 14 can be evacuated by means of a compound vacuum pump 16. In this example, the vacuum pump has two pumping sections in the form of two sets 18, 20 of turbo-molecular stages, and a third pumping section in the form of a Holweck drag mechanism 22; an alternative form of drag mechanism, such as a Siegbahn or Gaede mechanism, could be used instead. Each set 18, 20 of turbo-molecular stages comprises a number (three shown in Figure 1, although any suitable number could be provided) of rotor 19a, 21a and stator 19b, 21b blade pairs of known angled construction. The Holweck mechanism 22 includes a number (two shown in Figure 1 although any suitable number could be provided)

of rotating cylinders 23a and corresponding annular stators 23b and helical channels in a manner known per se.

In this example, a first pump inlet 24 is connected to the high vacuum chamber 10, and fluid pumped through the inlet 24 passes through both sets 18, 20 of turbo-molecular stages in sequence and the Holweck mechanism 22 and exits the pump via outlet 30. A second pump inlet 26 is connected to the third interface chamber 14, and fluid pumped through the inlet 26 passes through set 20 of turbo-molecular stages and the Holweck mechanism 22 and exits the pump via outlet 30. In this example, the pump 16 also includes a third inlet 27 which can be selectively opened and closed and can, for example, make the use of an internal baffle 27a to guide fluid into the pump 16 from the second, optional interface chamber 12. With the third inlet open, fluid pumped through the third inlet 27 passes through the Holweck mechanism only and exits the pump via outlet 30. In this example, the first interface chamber 11 is connected to a backing pump 32, which also pumps fluid from the outlet 30 of the compound vacuum pump 16. The backing pump typically pumps a mass flow of the same order of magnitude directly from the first chamber 11 as that from the outlet of the secondary vacuum pump 30. As fluid entering each pump inlet passes through a respective different number of stages before exiting from the pump, the pump 16 is able to provide the required vacuum levels in the chambers 10, 12, 14, with the backing pump 32 providing the required vacuum level in the chamber 11.

The backing pump 32 is typically a relatively large, floor standing pump.

Depending on the type of backing pump used, the performance provided by the backing pump at the first interface chamber 11 can be significantly affected by the operational frequency. For example, a direct on line backing pump running from a 50Hz electrical supply can produce a performance in the first chamber 11 as much as a 20% lower than the performance produced by the same pump operating at 60Hz. As the remaining chambers 10, 12, 14 are all linked to the first chamber 11, any change in the performance in the first chamber 11 would have a significant affect on the performance in the other chambers.

In at least its preferred embodiments, the present invention seeks to solve these and other problems.

In a first aspect, the present invention provides a differentially pumped mass spectrometer system comprising a mass spectrometer having a plurality of pressure chambers; and a vacuum pump attached thereto and comprising a plurality of pump inlets each for receiving fluid from a respective pressure chamber and a plurality of pumping stages for differentially pumping fluid from the chambers; whereby, in use, at least 99% of the fluid mass pumped from the spectrometer passes through the vacuum pump.

The differentially pumped mass spectrometer system may have additional, lower pressure chambers than those described above, which may be pumped by the same pumping arrangement or by a separate pumping arrangement. However, in either case, the fluid mass pumped through these additional lower pressure chambers is typically much less than 1% of the total system mass flow.

In one arrangement, the pump comprises at least three pump inlets, an outlet from a first, relatively low, pressure chamber being connected to a first pump inlet, an outlet for a second, medium pressure chamber of the spectrometer being connected to a second pump inlet, and an outlet for a third, highest pressure chamber of the spectrometer being connected to a third pump inlet.

Preferably, the pump comprises at least three pumping sections, each comprising at least one pumping stage, for differentially pumping the first to third chambers.

Preferably, the pump comprises a first pumping section, a second pumping section downstream from the first pumping section, and a third pumping section downstream from the second pumping section, the sections being arranged such that fluid entering the pump from the first chamber passes through the first, second and third pumping sections towards the pump outlet, fluid entering the pump from the second chamber passes through, of said sections, only the second and third

pumping sections towards the pump outlet, and fluid entering the pump from the third chamber passes through, of said sections, only the third pumping section towards the pump outlet.

- 5 Preferably at least one of the first and second pumping sections comprises at least one turbo-molecular stage. Both of the first and second pumping sections may comprise at least one turbo-molecular stage. The stage of the first pumping section may be of a different size to the stage of the second pumping section. For example, the stage of the second pumping section may be larger than the stage of
10 the first pumping section to offer selective pumping performance.

Optionally, the third pumping section is arranged such that fluid passing therethrough from the second pump inlet follows a different path from fluid passing
15 therethrough from the third pump inlet. For example, the third pumping section may be arranged such that fluid passing therethrough from the third pump inlet follows only part of the path of the fluid passing therethrough from the second pump inlet. Alternatively, the third pumping section may be arranged such that fluid passing therethrough from the third pump inlet follows a path which is
20 separate from the path of the fluid passing therethrough from the second pump inlet. For example, the third pumping stage may comprise a plurality of channels, in which one or more of the channels communicate with the second pump inlet whilst the remaining channels communicate with the third pump inlet. The third pumping section preferably comprises a multi-stage molecular drag mechanism. Preferably, the molecular drag mechanism is a multi-stage Holweck
25 mechanism with a plurality of channels arranged as a plurality of helices.

The vacuum pump may comprise a fourth inlet through which fluid can enter the pump from an additional chamber located between the second and third chambers and pass through the third pumping section only towards the pump outlet. The
30 third pumping section may be arranged such that fluid passing therethrough from the third pump inlet may follow a different path than fluid passing therethrough from the fourth pump inlet.

In one embodiment, the vacuum pump comprises an additional pumping section downstream from the third pumping section. For example, the additional pumping section may be an aerodynamic pumping mechanism such as a regenerative stage. Other types of aerodynamic mechanism may be side flow, side channel, and peripheral flow mechanisms.

Thus, in a second aspect, the present invention provides a differentially pumped mass spectrometer system comprising a mass spectrometer having a plurality of pressure chambers; and a vacuum pump attached thereto and comprising a plurality of pump inlets each for receiving fluid from a respective pressure chamber and a plurality of pumping stages for differentially pumping the chambers; wherein at least one of the pumping stages arranged to pump fluid from the pressure chamber in which the highest pressure is to be generated comprises an aerodynamic pumping stage.

Preferably, in use, the pressure of the fluid exhaust from the pump outlet is equal to or greater than 10 mbar.

The system preferably comprises a backing pump connected to the pump outlet such that, in use, at least 99% of the fluid mass pumped from the spectrometer passes through both the vacuum pump and the backing pump.

In a third aspect, the present invention provides a compound multi port vacuum pump comprising first, second, third and fourth pumping sections, a first pump inlet through which fluid can enter the pump and pass through each of the pumping sections towards a pump outlet, a second pump inlet through which fluid can enter the pump and pass through only the second, third and fourth pumping sections towards the outlet, a third pump inlet through which fluid can enter the pump and pass through only the third and fourth pumping sections towards the outlet, and a fourth inlet through which fluid can enter the pump and pass through only one, or both, of the third and fourth pumping sections towards the outlet.

One of the third and fourth pumping sections may be arranged such that fluid passing therethrough from the third pump inlet follows a different path than fluid passing therethrough from the fourth pump inlet. For example, the third pumping section may be arranged such that fluid passing therethrough from the fourth pump inlet follows only part of the path of the fluid passing therethrough from the third pump inlet. Alternatively, the third pumping section may be arranged such that fluid passing therethrough from the fourth pump inlet follows a path which is separate from the path of the fluid passing therethrough from the second pump inlet. For example, the third pumping stage may comprise a plurality of channels, in which one or more of the channels communicate with the third pump inlet whilst the remaining channels communicate with the fourth pump inlet. The third pumping section preferably comprises a multi-stage molecular drag mechanism. Preferably, the molecular drag mechanism is a multi-stage Holweck mechanism with a plurality of channels arranged as a plurality of helices.

Preferably, at least one of the first and second pumping sections comprises at least one turbo-molecular stage. The fourth pumping section preferably comprises a molecular drag stage or regenerative aerodynamic pumping stage (depending upon system performance requirements).

The pump preferably comprises a drive shaft having mounted thereon at least one rotor element for each of the various pumping sections. The rotor elements for at least the turbo-molecular stages may be integral with the drive shaft. The rotor elements for the aerodynamic stage may also be integral with the drive shaft. The rotor element of the third section may surround the rotor elements of the fourth section.

In a fourth aspect, the present invention provides an impeller for a vacuum pump, the impeller comprising a shaft having mounted thereon at least one rotor element for each of a turbomolecular stage and a molecular drag stage of the pump, and a plurality of rotors for an aerodynamic stage of the pump, wherein the rotor element

of the molecular drag stage surrounds the rotor elements of the aerodynamic stage.

The molecular drag stage may comprise a Holweck stage comprising at least one
5 rotating cylinder mounted for rotary movement with the rotor elements of the aerodynamic stage, which may be a regenerative mechanism. The cylinder may be mounted on a disc located on the drive shaft, which is preferably integral with the drive shaft.

10 Preferably, the pump comprises a common stator for at least one molecular drag stage and each of the aerodynamic stages. Thus, in a fifth aspect the present invention provides a vacuum pump comprising at least one molecular drag stage and at least one aerodynamic stage, a drive shaft having mounted thereon at least one rotor element for the molecular drag stage and a plurality of rotors for the
15 aerodynamic stage, and a common stator for both at least one molecular drag stage and each aerodynamic stage.

The present invention also provides a differentially pumped mass spectrometer
system comprising a plurality of chambers and a pump as aforementioned for
20 evacuating each of the chambers. The system preferably comprises a backing pump having an inlet connected to the pump outlet for receiving fluid exhaust from the pump.

Preferred features of the present invention will now be described, by way of
25 example only, with reference to the accompanying drawings, in which:

Figure 1 is a simplified cross-section through a known multi port vacuum pump suitable for evacuating a differentially pumped, mass spectrometer system;

30 Figure 2 is a simplified cross-section through a first embodiment of a multi port vacuum pump suitable for evacuating the differentially pumped mass spectrometer system of Figure 1;

Figure 3 is a simplified cross-section through a second embodiment of a multi port vacuum pump suitable for evacuating the differentially pumped mass spectrometer system of Figure 1; and

5

Figure 4 is a simplified cross-section through the impeller of the pump shown in Figure 3.

Figure 2 illustrates a first embodiment of a compound multi port vacuum pump 100
10 suitable for evacuating more than 99% of the total mass flow in the differentially pumped mass spectrometer system described above with reference to Figure 1. This is achieved by the vacuum pump 100 being arranged so as to be able to pump directly the highest pressure chamber, in addition to the usual second and third highest pressure chambers. The compound multi port vacuum pump 100
15 comprises a multi-component body 102 within which is mounted a drive shaft 104. Rotation of the shaft is effected by a motor (not shown), for example, a brushless dc motor, positioned about the shaft 104. The shaft 104 is mounted on opposite bearings (not shown). For example, the drive shaft 104 may be supported by a hybrid permanent magnet bearing and oil lubricated bearing system:

20

The pump includes at least three pumping sections 106, 108, 112. The first pumping section 106 comprises a set of turbo-molecular stages. In the embodiment shown in Figure 2, the set of turbo-molecular stages 106 comprises four rotor blades and three stator blades of known angled construction. A rotor
25 blade is indicated at 107a and a stator blade is indicated at 107b. In this example, the rotor blades 107a are integral with the drive shaft 104.

The second pumping section 108 is similar to the first pumping section 106, and also comprises a set of turbo-molecular stages. In the embodiment shown in
30 Figure 2, the set of turbo-molecular stages 108 also comprises four rotor blades and three stator blades of known angled construction. A rotor blade is indicated at

109a and a stator blade is indicated at 109b. In this example, the rotor blades 109a are also integral with the drive shaft 104.

Downstream of the first and second pumping sections is a third pumping section

5 112 in the form of a molecular drag mechanism, for example, a Holweck drag mechanism. In this embodiment, the Holweck mechanism comprises two rotating cylinders 113a, 113b and corresponding annular stators 114a, 114b having helical channels formed therein in a manner known per se. The rotating cylinders 113a, 113b are preferably formed from a carbon fibre material, and are mounted on a
10 disc 115, which is located on the drive shaft 104. In this example, the disc 115 is also integral with the drive shaft 104.

Downstream of the Holweck mechanism 112 is a pump outlet 116. A backing pump 150 backs the pump 100 via outlet 116.

15 As illustrated in Figure 2, the pump 100 has three inlets 120, 122, 124; although only three inlets are used in this embodiment, the pump may have a fourth inlet indicated at 126, which can be selectively opened and closed and can, for example, make the use of internal baffles 127 to guide different flow streams to
20 particular portions of a mechanism. The first, low fluid pressure inlet 120 is located upstream of all of the pumping sections. The second, middle fluid pressure inlet 122 is located interstage the first pumping section 106 and the second pumping section 108. The third, low fluid pressure inlet 124 may be located upstream of or, as illustrated in Figure 2, between the stages of the
25 Holweck mechanism 112, such that all of the stages of the Holweck mechanism are in fluid communication with the first and second inlets 120, 122, whilst, in the arrangement illustrated in Figure 2, only a portion (one or more) of the stages are in fluid communication with the third inlet 124. The fourth, optional inlet 126 is located interstage the second pumping section 108 and the Holweck mechanism
30 112, such that all of the stages of the Holweck mechanism 112 are in fluid communication with the fourth inlet 126.

In use, each inlet is connected to a respective chamber of the differentially pumped mass spectrometer system. Thus, the first inlet 120 is connected to a low pressure chamber 10; the second inlet 122 is connected to a middle pressure chamber 14 and the third inlet 124 is connected to the highest pressure chamber

5 11. Where a fourth chamber 12 is present between the high pressure chamber 11 and the middle pressure chamber 14, as indicated by the dotted line 140, the fourth inlet 126 is opened and connected to the fourth chamber 12. Additional lower pressure chambers may be added to the system, and may be pumped by separate means, however, the mass flow of these additional chambers is typically
10 much less than 1% of the total mass flow of the spectrometer system.

Fluid passing through the first inlet 120 from the low pressure chamber 10 passes through the first pumping section 106, through the second pumping section 108, through all of the channels of the Holweck mechanism 112 and exits the pump 100
15 via pump outlet 116. Fluid passing through the second inlet 122 from the middle pressure chamber 14 enters the pump 100, passes through the second pumping section 108, through all of the channels of the Holweck mechanism 112 and exits the pump 100 via pump outlet 116. Fluid passing through the third inlet 124 from
20 the high pressure chamber 11 enters the pump 100, passes through at least a portion of the channels of the Holweck mechanism and exits the pump via pump outlet 116. If opened, fluid passing through the fourth inlet 126 from the fourth chamber 12 enters the pump 100, passes through all of the channels of the Holweck mechanism 112 and exits the pump 100 via pump outlet 116.

25 In this example, in use, and similar to the system described with reference to Figure 1, the first interface chamber 11 is at a pressure of around 1-10 mbar, the second interface chamber 12 (where used) is at a pressure of around 10^{-1} -1 mbar, the third interface chamber is at a pressure of around 10^{-2} - 10^{-3} mbar, and the high vacuum chamber is at a pressure of around 10^{-5} - 10^{-6} mbar.

30 A particular advantage of the embodiment described above is that, by enabling the high pressure chamber of the differentially pumped mass spectrometer system to

be directly pumped by the same compound multi port vacuum pump 100 that pumps the second and third highest pressure chambers, rather than by the backing pump 150, the compound multi port vacuum pump is able to manage more than 99% of the total fluid mass flow of the mass spectrometer system.

Thus, the performance of the first chamber and the rest of the internally linked spectrometer system can be increased without increasing the size of the backing pump.

Figure 3 provides a second embodiment of a vacuum pump 200 suitable for evacuating more than 99% of the total mass flow from a differentially pumped mass spectrometer system and is similar to the first embodiment, save that a fourth pumping section 210, in this example in the form of an aerodynamic regenerative stage, is located downstream of the Holweck stage 212.

The regenerative stage 210 comprises a plurality of rotors in the form of an annular array of raised rings 211a mounted on, or integral with, the disc 215 of the Holweck mechanism 212. As illustrated in Figure 4, in this embodiment, rotors 107, 109, of the turbo-molecular sections 106, 108, the rotating disc 215 of the Holweck mechanism 212 and the rotors 211a of the regenerative section 210 are integral with the drive shaft 204, with the carbon fibre rotating cylinder 213a of the Holweck mechanism 212 being mounted on the rotating disc 215 following machining of these integral rotary elements.

Stator 214b of the Holweck mechanism 212 can also form the stator of the regenerative stage 210, and has formed therein an annular channel 211b within which the rotors 211a rotate. As is known, the channel 211b has a cross sectional area greater than that of the individual rotors 211a, except for a small part of the channel known as a "stripper" which has a reduced cross section providing a close clearance for the rotors. In use of the pump 200, fluid pumped from each of the chambers of the differentially pumped mass spectrometer system enters the annular channel 211b via an inlet positioned adjacent one end of the stripper and the fluid is urged by means of the rotors 211a on the rotating disc 215 along the

channel 211b until it strikes the other end of the stripper, and the fluid is then urged through the outlet 216 situated on that other end of the stripper.

In use, the vacuum pump 200 can generate a similar performance advantage in the chambers of the differentially pumped mass spectrometer system as the vacuum pump 100 of the first embodiment. In addition to the potential performance advantage offered by the first embodiment, this second embodiment can also offer two further distinct advantages. The first of these is the consistency of the system performance when backed by pumps with different levels of performance, for example a backing pump operating directly on line at 50 or 60Hz. In the case of this second embodiment it is anticipated that, in the system described with reference to Figure 3, the variation in system performance will be as low as 1% if the frequency of operation of the backing pump 250 is varied between 50Hz and 60Hz, thus providing the user with a flexible pumping arrangement with stable system performance. The second additional advantage of the second embodiment is that by providing an additional pumping section downstream of the Holweck section, this arrangement of the vacuum pump can enable the capacity, and thus the size, of the backing pump 250 to be significantly reduced in comparison to the first embodiment. This is because, by virtue of the additional pumping section 210, the vacuum pump 200 can exhaust fluid at a pressure of above 10mbar. In contrast, the vacuum pump 100 of the first embodiment typically exhausts fluid at a pressure of around 1-10 mbar, and so the size of the backing pump 250 can be reduced significantly in comparison to the backing pump 150 of the first embodiment. It is anticipated that this size reduction could be as much as a factor of 10 in some mass spectrometer systems without adversely affecting system performance. As indicated in Figures 3 and 4, the rotors 211a of the regenerative section 210 are surrounded by the rotating cylinder 213a of the Holweck section 212. Thus, the regenerative section 210 can be conveniently included in the vacuum pump 100 of the first embodiment with little, or no, increase in the overall length of the vacuum pump. Thus, the whole pumping system of the second embodiment, including both vacuum pump 200 and backing

pump 250, could be reduced in size and possibly conveniently housed within a bench-top mounted enclosure.

5 In summary, differentially pumped mass spectrometer system comprises a mass spectrometer having a plurality of pressure chambers; a vacuum pump attached thereto and comprising at least three pump inlets, a first pumping section, a second pumping section downstream from the first pumping section, and a third pumping section downstream from the second pumping section, an outlet from a first, relatively low, pressure chamber being connected to a first pump inlet through which fluid can enter the pump from the first chamber and pass through the first, 10 second and third pumping sections towards a pump outlet, an outlet for a second, medium pressure chamber of the spectrometer being connected to a second pump inlet through which fluid can enter the pump and pass through, of said sections, only the second and third pumping sections towards the pump outlet, 15 and an outlet for a third, highest pressure chamber of the spectrometer being connected to a third pump inlet through which fluid can enter the pump and pass through, of said sections, only the third pumping section towards the pump outlet; and a backing pump connected to the pump outlet such that, in use, at least 99% 20 of the fluid mass pumped from the spectrometer passes through both the vacuum pump and the backing pump.

CLAIMS

1. A differentially pumped mass spectrometer system comprising a mass spectrometer having a plurality of pressure chambers; and a vacuum pump attached thereto and comprising a plurality of pump inlets each for receiving fluid from a respective pressure chamber and a plurality of pumping stages for differentially pumping fluid from the chambers; whereby, in use, at least 99% of the fluid mass pumped from the spectrometer passes through the vacuum pump.
2. A system according to Claim 1, wherein the pump comprises at least three pump inlets, an outlet from a first, relatively low, pressure chamber being connected to a first pump inlet, an outlet for a second, medium pressure chamber of the spectrometer being connected to a second pump inlet, and an outlet for a third, highest pressure chamber of the spectrometer being connected to a third pump inlet.
3. A system according to Claim 2, wherein the pump comprises at least three pumping sections, each comprising at least one pumping stage, for differentially pumping the first to third chambers.
4. A system according to Claim 3, wherein the pump comprises a first pumping section, a second pumping section downstream from the first pumping section, and a third pumping section downstream from the second pumping section, the sections being arranged such that fluid entering the pump from the first chamber passes through the first, second and third pumping sections towards the pump outlet, fluid entering the pump from the second chamber passes through, of said sections, only the second and third pumping sections towards the pump outlet, and fluid entering the pump from the third chamber passes through, of said sections, only the third pumping section towards the pump outlet.

5. A system according to Claim 4, wherein at least one of the first and second pumping sections comprises at least one turbo-molecular stage.

5 6. A system according to Claim 4 or Claim 5, wherein both of the first and second pumping sections comprise at least one turbo-molecular stage.

10 7. A system according to any of Claims 4 to 6, wherein the third pumping section is arranged such that fluid passing therethrough from the second pump inlet follows a different path from fluid passing therethrough from the third pump inlet.

15 8. A system according to Claim 7, wherein the third pumping section is arranged such that fluid passing therethrough from the third pump inlet follows only part of the path of the fluid passing therethrough from the second pump inlet.

20 9. A system according to any of Claims 4 to 8, wherein the third pumping section comprises a multi-stage molecular drag mechanism.

10. A system according to Claim 9, wherein the molecular drag mechanism is a multi-stage Holweck mechanism with a plurality of channels arranged as a plurality of helixes.

25 11. A system according to any of Claims 4 to 10, wherein the vacuum pump comprises a fourth inlet through which fluid can enter the pump from an additional chamber located between the second and third chambers and pass through the third pumping section only towards the pump outlet.

12. A system according to Claim 11, wherein the third pumping section is arranged such that fluid passing therethrough from the third pump inlet may follow a different path than fluid passing therethrough from the fourth pump inlet.

5 13. A system according to any of Claims 4 to 12, comprising an additional pumping section downstream from the third pumping section.

10 14. A system according to Claim 13, wherein the additional pumping section comprises an aerodynamic pumping mechanism.

15 15. A differentially pumped mass spectrometer system comprising a mass spectrometer having a plurality of pressure chambers; and a vacuum pump attached thereto and comprising a plurality of pump inlets each for receiving fluid from a respective pressure chamber, and a plurality of pumping stages for differentially pumping the chambers; wherein at least one of the pumping stages arranged to pump fluid from the pressure chamber in which the highest pressure is to be generated comprises an aerodynamic pumping stage.

20 16. A system according to Claim 14 or Claim 15, wherein the aerodynamic pumping mechanism comprises a regenerative stage.

25 17. A system according to any of Claims 14 to 16, wherein, in use, the pressure of the fluid exhaust from the pump outlet is equal to or greater than 10 mbar.

30 18. A system according to any preceding claim, comprising a backing pump connected to the pump outlet such that, in use, at least 99% of the fluid mass pumped from the spectrometer passes through both the vacuum pump and the backing pump.

19. A differentially pumped mass spectrometer system substantially as herein described with reference to Figure 2 or Figure 3 of the accompanying drawings.

5 20. A compound multi port vacuum pump comprising first, second, third and fourth pumping sections, a first pump inlet through which fluid can enter the pump and pass through each of the pumping sections towards a pump outlet, a second pump inlet through which fluid can enter the pump and pass through only the second, third and fourth pumping sections towards the outlet, a third pump inlet through which fluid can enter the pump and pass through only the third and fourth pumping sections towards the outlet, and a fourth inlet through which fluid can enter the pump and pass through only one, or both, of the third and fourth pumping sections towards the outlet.

15 21. A pump according to Claim 20, wherein one of the third and fourth pumping sections is arranged such that fluid passing therethrough from the third pump inlet follows a different path than fluid passing therethrough from the fourth pump inlet.

20 22. A pump according to Claim 20 or Claim 21, wherein the third pumping section is arranged such that fluid passing therethrough from the fourth pump inlet follows only part of the path of the fluid passing therethrough from the third pump inlet.

25 23. A pump according to any of Claims 20 to 22, wherein the third pumping section comprises a multi-stage molecular drag mechanism.

30 24. A pump according to Claim 23, wherein the molecular drag mechanism is a multi-stage Holweck mechanism with a plurality of channels arranged as a plurality of helices.

25. A pump according to any of Claims 20 to 24, wherein at least one of the first and second pumping sections comprises at least one turbo-molecular stage.

26. A pump according to any of Claims 20 to 25, wherein both of the first and second pumping sections comprise at least one turbo-molecular stage.

27. A pump according to any of Claims 20 to 26, wherein the fourth pumping section comprises an aerodynamic pumping mechanism.

28. A pump according to any of Claims 20 to 27, wherein the fourth pumping section comprises a regenerative stage.

29. A pump according to any of Claims 20 to 28, comprising a drive shaft having mounted thereon at least one rotor element for each of the pumping sections.

30. A pump according to Claim 29, wherein the rotor elements for at least the first and second pumping sections are integral with the drive shaft.

31. A pump according to Claim 30, wherein the rotor elements for at least the first, second and fourth pumping sections are integral with the drive shaft.

32. A pump according to any of Claims 20 to 31, wherein the rotor element of the third pumping section surround the rotor elements of the fourth pumping section.

33. An impeller for a vacuum pump, the impeller comprising a shaft having mounted thereon at least one rotor element for each of a turbomolecular stage and a molecular drag stage of the pump, and a plurality of rotors for an aerodynamic stage of the pump, wherein the rotor element of the molecular drag stage surrounds the rotor elements of the aerodynamic stage.

34. An impeller according to Claim 33, wherein the rotor element for the molecular drag stage comprises at least one rotating cylinder mounted for rotary movement with the rotor elements of the aerodynamic stage.

35. An impeller according to Claim 34, wherein the cylinder is mounted on a disc located on the drive shaft.

36. An impeller according to Claim 35, wherein the disc is integral with the drive shaft.

37. A vacuum pump comprising an impeller as claimed in any of Claims 33 to 36.

38. A pump according to Claim 37, comprising a common stator for at least one molecular drag stage and each aerodynamic stage.

39. A vacuum pump comprising a molecular drag stage and at least one aerodynamic stage, a drive shaft having mounted thereon at least one rotor element for the molecular drag stage and a plurality of rotors for the aerodynamic stage, and a common stator for both at least one molecular drag stage and each aerodynamic stage.

40. A vacuum pump substantially as herein described with reference to Figure 2 or Figure 3 of the accompanying drawings.

41. An impeller for a vacuum pump substantially as herein described with reference to Figure 4 of the accompanying drawings.
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ABSTRACT

A differentially pumped mass spectrometer system comprises a mass spectrometer having a plurality of pressure chambers; a vacuum pump attached thereto and comprising at least three pump inlets, a first pumping section, a second pumping section downstream from the first pumping section, and a third pumping section downstream from the second pumping section, an outlet from a first, relatively low, pressure chamber being connected to a first pump inlet through which fluid can enter the pump from the first chamber and pass through the first, second and third pumping sections towards a pump outlet, an outlet for a second, medium pressure chamber of the spectrometer being connected to a second pump inlet through which fluid can enter the pump and pass through, of said sections, only the second and third pumping sections towards the pump outlet, and an outlet for a third, highest pressure chamber of the spectrometer being connected to a third pump inlet through which fluid can enter the pump and pass through, of said sections, only the third pumping section towards the pump outlet; and a backing pump connected to the pump outlet such that, in use, at least 99% of the fluid mass pumped from the spectrometer passes through both the vacuum pump and the backing pump.

(Figure 2)

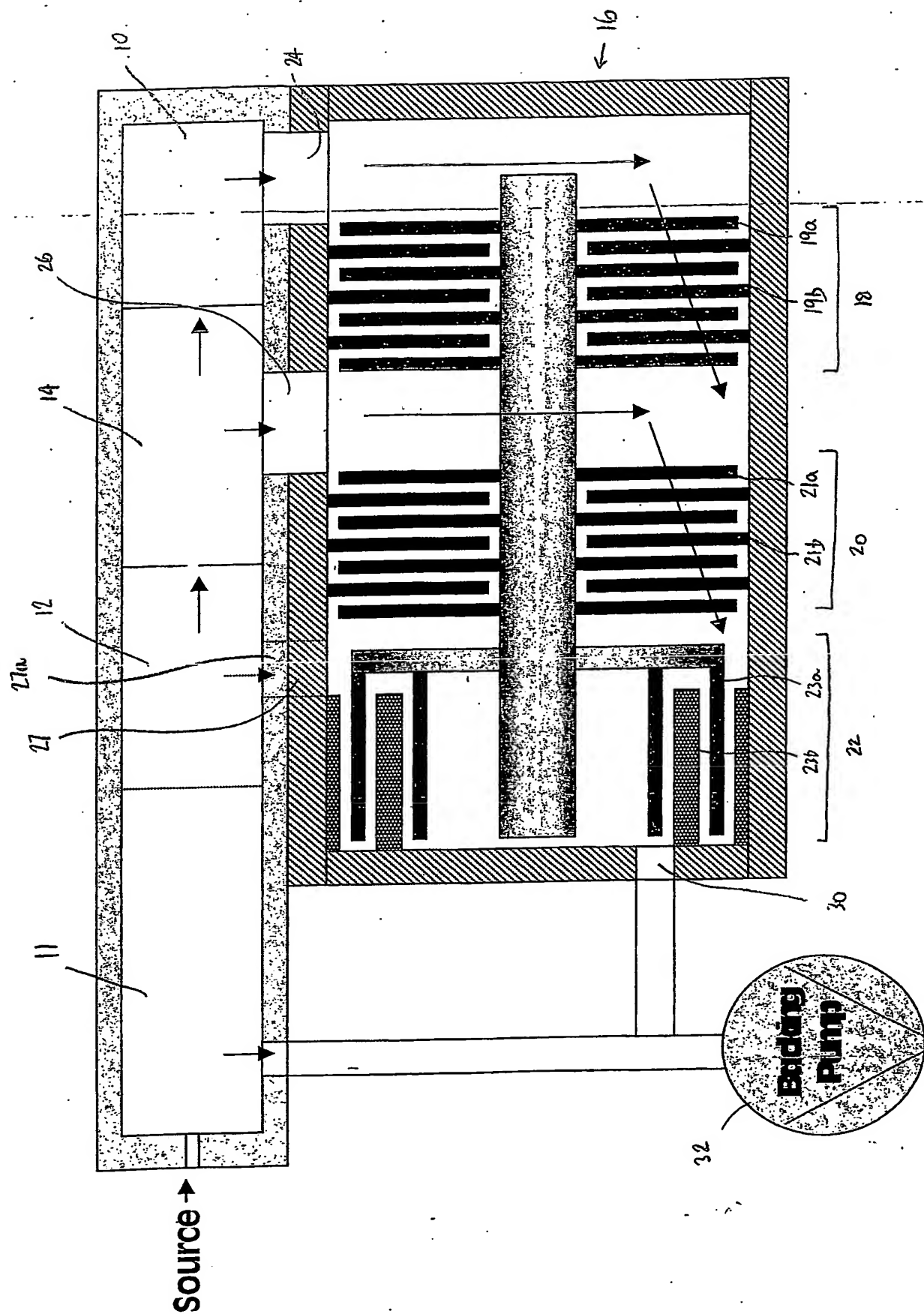


FIG. 1 (PRIOR ART)

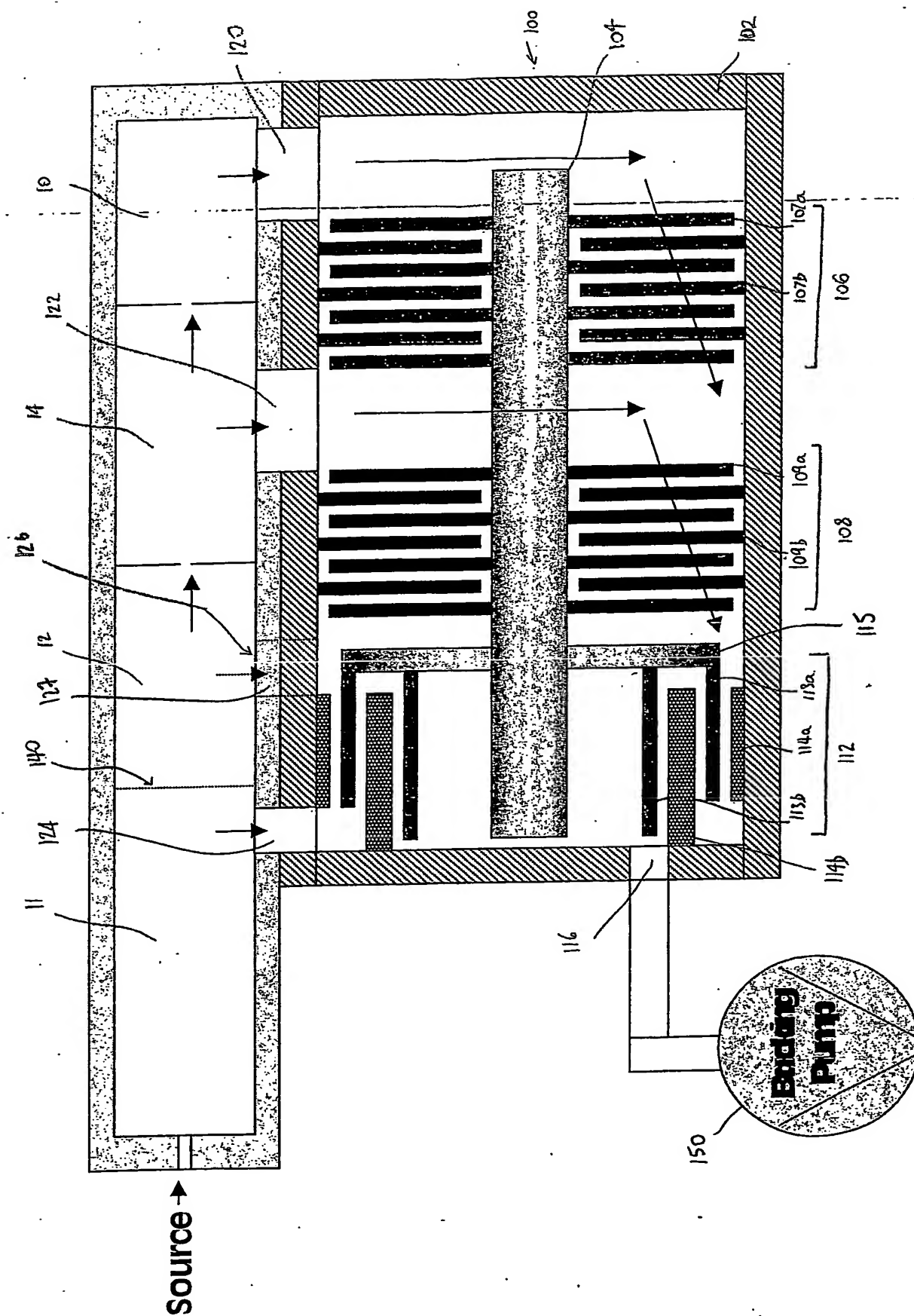


FIG. 2

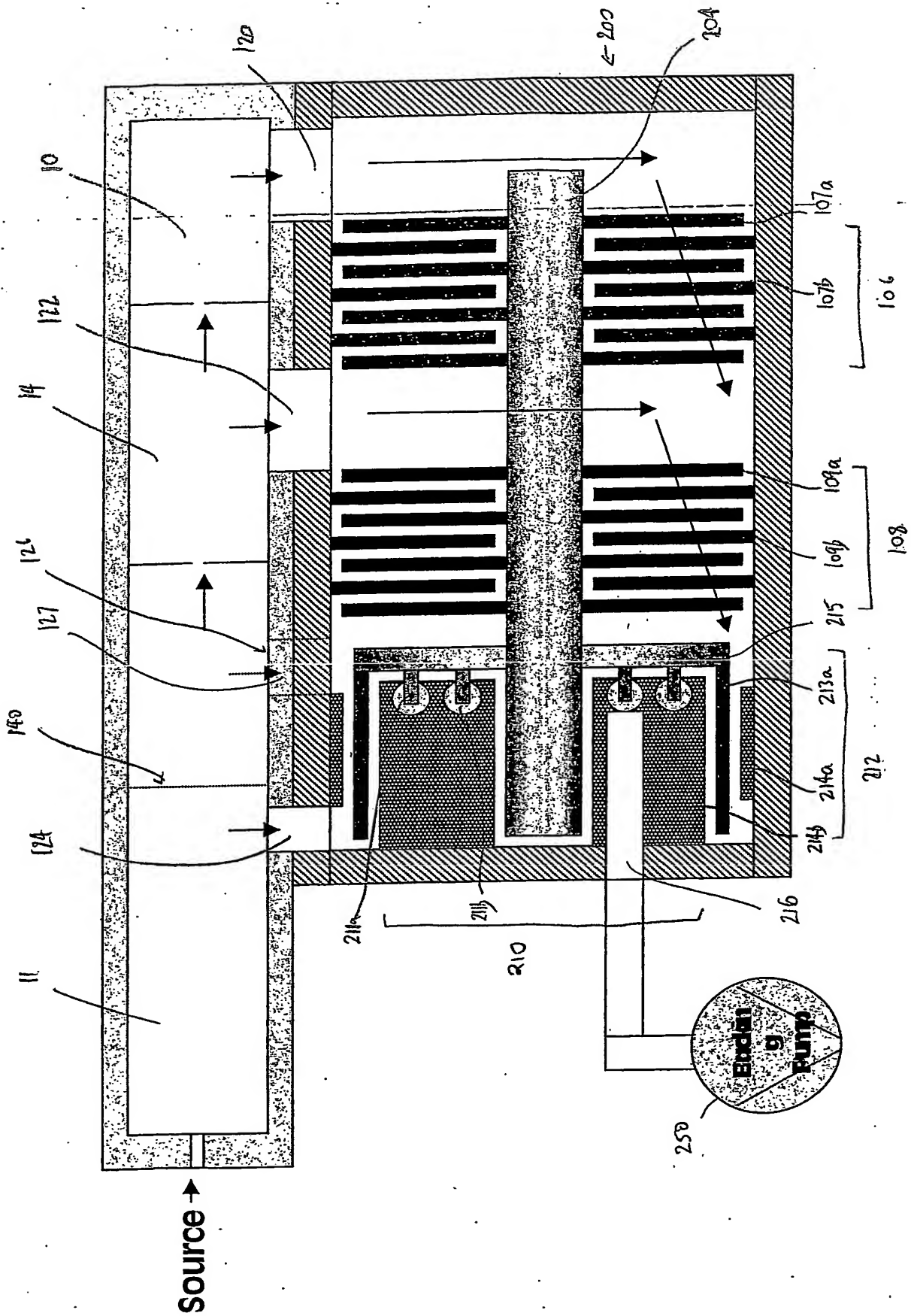


Fig. 3

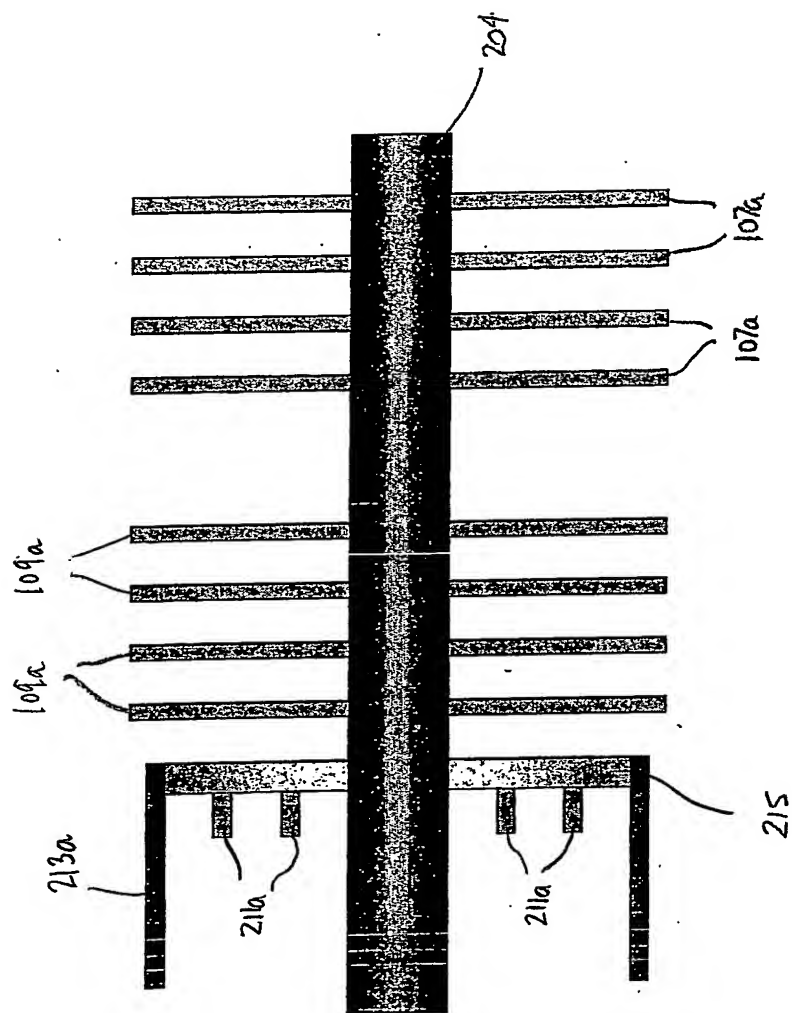


FIG. 4



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